Is There a Classical Analog of a Quantum Time-Translation Machine?

Lev Vaidman

School of Physics and Astronomy

Raymond and Beverly Sackler Faculty of Exact Sciences

Tel–Aviv University, Tel–Aviv 69978 ISRAEL

ABSTRACT

In a recent article [D. Suter, Phys. Rev. **A 51**, 45 (1995)] Suter has claimed to present an optical implementation of the quantum time-translation machine which "shows all the features that the general concept predicts and also allows, besides the quantum mechanical, a classical description." It is argued that the experiment proposed and performed by Suter does not have the features of the quantum time-translation machine and that the latter has no classical analog.

A quantum time machine, suggested by Aharonov et al. [1] and elaborated by Vaidman [2], is not a realistic device for a time travel. It is a gedanken procedure which, it seems, have no chance for practical implementation in a near future. Moreover, even on the level of a gedanken experiment, the machine usually fails to operate. Only very rarely it succeeds to operate, but if it does, it achieves what, as far as we know, no other machine can.

Let us spell out what this quantum time machine does when it succeeds to work. Let the time of the operation of the machine to be T and the time evolution parameter of the machine to be T'. If we put inside the time machine any system (which fulfills some general requirements of energy spectrum boundness) then, at the end of the operation, the system will evolve to the state in which it would have been after the undisturbed evolution of the time T' (instead of T). The important property is that we do not have to know which system was put inside and what was its initial state. Our machine has an indicator saying that the time-translation was accomplished successfully, and this without "looking" on the system inside.

There are two well known classical devices which perform this task. In fact, they achieve even more, since they work always, and there are less restrictions on what system can be put inside. The first device is a fast rocket which makes a round trip, and the second is a heavy massive shell which is placed around the system for a period of time. However, all classical time machines can change the effective evolution time from T to T' with the

restriction $0 < T' < T$, i.e., a classical time machine can only slow down the time evolution. Contrary to this, in the quantum time machine the parameter T' can have an arbitrary value. For $T' > T$ it speeds up the time evolution and for $T' < 0$ it effectively changes the direction of the time flow. Neither of these effects can be achieved classically.

Suter [3] has claimed to perform an experimental realization of the quantum time-translation machine using a classical Mach-Zehnder interferometer, and he concluded that the time-translation effect of the proposed quantum time machine is "not specific to quantum mechanics, but is well known in classical field theory." The experimental setup of Suter, however, does not fall even close to the definition of the time machine. In his setup we know what is the system and what is its initial state. What he shows is that if we send a single mode of a radiation field through a birefringent retardation device which yields different retardations for two orthogonal polarizations, then placing the pre-selection polarization filter and the post-selection polarization filter will lead to a much larger effect than for any of the pre-selected only polarizations. So, it might seem like speeding up the time evolution, but this procedure fails all tests of universality. Different modes of radiation field speed up differently, an arbitrary wave packet is usually distorted, and for other systems (other particles) the device is not supposed to work at all.

So the first basic requirement that the time machine has to work for various systems is not fulfilled from the beginning. And it cannot be easily

modified since the "external" variable (which is supposed to be a part of the time-machine) is the property of the system itself – the polarization of the radiation field. The next necessary requirement, that it works for a large class of the initial states of the system, cannot be fulfilled too. Indeed, he considers a superposition of only two time evolutions. This superposition can be identical to a longer evolution for a particular state, but not for a large class of states. As it has been shown [1, 2] a superposition of a large number of time evolutions is necessary for this purpose.

We have shown that the experiment of Suter is not an implementation of the quantum time machine. Still, it can be interpreted as a *weak measurement* [4, 5]. The experiment of Suter with a birefringent retardation device can be considered as a weak measurement of a polarization operator. In fact, this is a variation of the experiments which were proposed [6] and performed [7] previously. In the first proposal, a birefringent prism caused an unusually large deflection of a well localized beam with pre- and post-selected polarization. And, in the experiment which was successfully performed [7], a birefringent plate was used instead. The "weakness condition" of these two experiments follows from the localization of the beam (which was sent through a narrow slit). The "weak" regime of the experiment of Suter is achieved by taking the retardation small, $\delta << \pi$.

All these three experiments can be explained both as quantum experiments on the ensembles of photons or as "classical" experiments with elec-

tromagnetic waves. We believe, however, that the correct way to consider the weak measurement effect is as a genuine effect of quantum mechanics. First, because it has no analog in classical *mechanics*. Second, because in general, it has also no explanation in terms of classical *waves*. As we shall explain below, it is an accidental fact that all performed weak measurement experiments can be explained in terms of classical waves.

According to the conceptual procedure of weak measurements, we start with an ensemble of systems prepared in the same state, we perform (weak) measurements with the measuring devices (one labeled device for each system), we make post-selection measurements on all systems, we discard all the result of the measuring devices which correspond to the systems which did not yield the appropriate result in the post-selection measurement, and finally we make statistical analysis (calculating the avarage) of the readings of the remaining measuring devices. All actually performed weak measurements had the property that the pointer variables of the measuring devices were the variables of the systems themselves. This property made the weak measurement much easier to perform, but it is in no way a necessary property of weak measurements. This is, however, a necessary property for having explanation in terms of classical waves. If the measuring device and the measured system are indeed different systems, than the weak measurement effect follows from the quantum correlations between these two systems which have no classical analog. Even if the variable of the measuring device is a variable

of the system itself (which makes the post-selection much easier to perform), the classical explanation is not necessarily granted. The experiments which were performed used lasers, i.e., classical sources of light. However, nobody doubts that the same results would be obtained if sources of single photons were used instead, and these experiments have no classical description.

We also question the claim of Suter, that the interference effect of classical waves, which appears in certain weak measurements, is well known. It is well known, indeed, that pre- and post-selection might lead to unusual interference effects. However, the point of the weak measurements is not just that the final superposition is very different from its components, but that it has a particular form described by a very general and simple formula [5]. The final distribution has (almost) the same form as the initial one, and its center is shifted to a well defined value, given by the *weak value* of the measured quantity A, $A_w \equiv \langle\Psi_2|A|\Psi_1\rangle/\langle\Psi_2|\Psi_1\rangle$, where $|\Psi_1\rangle$ is the pre-selected state and $|\Psi_2\rangle$ is the post-selected state. We do not know that this remarkable feature was ever seen before.

We want to mention here that Suter, together with R. Ernst and M. Ernst, performed in the past another experiment which they called "An experimental realization of a quantum time-translation machine" [8]. In this experiment a very different system was used: the effect was demonstrated on the heteronuclear coupling between two nuclear spins. But the experimental setup was also applicable only to a specific system and only for a certain state.

Therefore, the same criticism is applicable and, therefore, one should not call it an implementation of the time-translation machine. One might, however, consider it as another successful weak measurement, the weak measurement of a nuclear spin component.

References

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